FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: **WLJ.078**

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR): **10/018809**

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/GB00/02255	**21 JUNE 2000**	**21 JUNE 1999**

TITLE OF INVENTION

IMPROVEMENTS RELATING TO PLASMA ETCHING

APPLICANT(S) FOR DO/EO/US

Anand SRINIVASAN **Gunnar LANDGREN**
Carl-Fredrik CARLSTROM

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

UNEXECUTED Declaration and Power of Attorney

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/018809	PCT/GB00/02255	WLJ.078

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS PTO USE ONLY
☐	Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1040.00**	
☒	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$890.00**	
☐	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**	
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**	
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**	
	ENTER APPROPRIATE BASIC FEE AMOUNT =	**$890.00**
	Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
Total claims	19 - 20 =	0	x $18.00	**$0.00**
Independent claims	2 - 3 =	0	x $84.00	**$0.00**
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**
	TOTAL OF ABOVE CALCULATIONS =			**$890.00**
☐	Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.			**$0.00**
	SUBTOTAL =			**$890.00**
	Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +			**$0.00**
	TOTAL NATIONAL FEE =			**$890.00**
☒	Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			**$40.00**
	TOTAL FEES ENCLOSED =			**$930.00**
			Amount to be: refunded	$
			charged	$

a. ☒ A check in the amount of **$930.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **50-0238** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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33289
REGISTRATION NUMBER

DECEMBER 21, 2001
DATE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent application of	:	
Anand SRINIVASAN et al.	:	Box New Applications
Serial No. (new)	:	
Filed December 21, 2001	:	

IMPROVEMENTS RELATING TO PLASMA ETCHING

PRELIMINARY AMENDMENT

Honorable Commissioner For Patents
Washington, D.C. 20231

Sir:

Prior to the examination of the above-identified application, the following amendments and remarks are submitted:

In the Claims[1]

Kindly cancel Claim 12 without prejudice or disclaimer of its subject matter.

Kindly rewrite Claims 4-11 to read as follows:

[1] A marked-up copy of the original claims showing additions and deletions thereto is attached.

4. (Amended) The method according to Claim 1, wherein said etching gas is mixed with another gas selected from H_2, N_2, O_2, Ar or another rare gas, or Cl_2, BCl_3 or other halogen-containing gas or any combination of these.

5. (Amended) A method according to Claim 1, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power with a magnetic field to the etching gas.

6. (Amended) A method according to Claim 1, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power to the etching gas.

7. (Amended) A method according to Claim 1, wherein said step (a) comprises forming the gas into a plasma by supplying radio frequency electric power to the etching gas.

8. (Amended) A method according to Claim 1, wherein said step (a) comprises forming the gas into a plasma by supplying DC electric power to the etching gas.

9. (Amended) A method according to Claim 1, wherein the ions are accelerated by

a DC bias.

11. (Amended) A method according to Claim 1, wherein the applied power is converted to an ion energy in the range of 0-2000 eV.

Please add the following new Claims 13-20:

13. The method according to Claim 3, wherein said etching gas is mixed with another gas selected from H_2, N_2, O_2, Ar or another rare gas, or Cl_2, BCl_3 or other halogen-containing gas or any combination of these.

14. A method according to Claim 3, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power with a magnetic field to the etching gas.

15. A method according to Claim 3, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power to the etching gas.

16. A method according to Claim 3, wherein said step (a) comprises forming the gas into a plasma by supplying radio frequency electric power to the etching gas.

17. A method according to Claim 3, wherein said step (a) comprises forming the gas into a plasma by supplying DC electric power to the etching gas.

18. A method according to Claim 3, wherein the ions are accelerated by a DC bias.

19. A method according to Claim 18, wherein said DC bias creates energy in the range of 0-2000 eV.

20. (Amended) A method according to Claim 1, wherein the applied power is converted to an ion energy in the range of 0-2000 eV.--

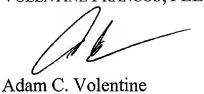
REMARKS

By this Preliminary Amendment, Claim 12 has been canceled, Claims 4-11 have been amended to eliminate multiple dependencies, and new Claims 13-20 have been added.

Entry of this Preliminary Amendment is respectfully requested.

Respectfully submitted,

VOLENTINE FRANCOS, PLLC



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Claims

1. A method of etching a substrate provided with pre-defined masked regions, whose elemental constituents are selected from Groups III and V or from groups II and VI of the Periodic Table, comprising the steps of: a) forming a gas containing molecules having at least one methyl group (CH_3) linked to nitrogen into a plasma; and b) etching the unmasked regions of the substrate by means of the plasma.

2. The method according to Claim 1, wherein said etching gas is selected from the group consisting of methylamine (CH_3NH_2), dimethylamine ($(CH_3)_2NH$) and trimethylamine ($(CH_3)_3N$).

3. A method of etching a substrate provided with pre-defined masked regions, whose elemental constituents are selected from Groups II and VI of the Periodic Table, comprising the steps of: a) forming an etching gas comprising trimethylamine ($(CH_3)_3N$) into a plasma; and b) etching the unmasked regions of the substrate by means of the plasma.

4. The method according to ~~any one of~~ Claims 1 ~~and 3~~, wherein said etching gas is mixed with another gas selected from H_2, N_2, O_2, Ar or another rare gas, or Cl_2, BCl_3 or other halogen-containing gas or any combination of these.

5. A method according to ~~any one of~~ Claims 1 ~~to 4~~, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power with a

MARKED-UP COPY OF ORIGINAL CLAIMS (1)

magnetic field to the etching gas.

6. A method according to ~~any one of~~ Claims 1 ~~to 4~~, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power to the etching gas.

7. A method according to ~~any one of~~ Claims 1 ~~to 4~~, wherein said step (a) comprises forming the gas into a plasma by supplying radio frequency electric power to the etching gas.

8. A method according to ~~any one of~~ Claims 1 ~~to 4~~, wherein said step (a) comprises forming the gas into a plasma by supplying DC electric power to the etching gas.

9. A method according to ~~any one of~~ Claims 1 ~~to 8~~, wherein the ions are accelerated by a DC bias.

10. A method according to Claim 9, wherein said DC bias creates energy in the range of 0-2000 eV.

11. A method according to ~~any one of~~ Claims 1 ~~to 8~~, wherein the applied power is converted to an ion energy in the range of 0-2000 eV.

~~12. Any combination of novel features of a method of~~ etching a substrate provided with pre-defined masked regions, substantially as herein described and/or as ~~illustrated in the accompanying drawings~~

Claims 13 to 20
- Repeat wordings of claims 4 to 11, but dependants upon claim 3.

(2)

"Improvements relating to plasma etching"

The present invention relates to a method of etching and finds particular application in the fields of opto-electronic, electronic and micro-mechanical device production.

Many semiconductor devices consist of at least one element selected of Group III and at least one element selected of Group V of the periodic table (III-V materials). Examples of such materials include indium phosphide (InP), gallium arsenide (GaAs), the ternary ($In_xGa_{1-x}As$) and the quaternary materials ($In_xGA_{1-x}As_yP_{1-y}$).

The production of semiconductor devices generally involves the processing of the surface of a solid substrate, either by etching or by deposition. A known method of processing a solid substrate is to expose the substrate to a plasma of a gas having the glow discharges of the gas molecules reacting chemically and/or physically with the substrate.

III-V materials can be etched using hydrocarbon gases. In the book by Avishay Katz "Indium Phosphide and Related Materials, Processing, Technology and Devices", Artech House Boston, London, methods of etching InP and related materials are described.

It is considered in the above book that etching of the substrate surface is caused by formation of volatile organometal species (i.e. methyl-III compounds e.g. $(CH_3)_xIn$) and hydrogen-V compounds.

The formation of organometal species, especially $(CH_3)_xIn$, is crucial since the V-elements, especially phosphorus, are volatile and depletion of the group V-element on the surface can occur. The enrichment of III-elements, especially indium, leads to the micro-masking effect where indium rich areas are more difficult to etch and thereby mask the underlying crystal resulting in rough surface morphology.

However, increase of the hydrocarbon etch gas to compensate with a higher indium methyl formation rate leads to formation of an etch inhibiting polymer film on the surface and severe polymer build-up on the mask.

It is one object of the present invention to provide a method of etching with enhanced etching of the III elements, avoiding preferential etching of the V elements.

According to the present invention, there is provided a method of etching a substrate provided with pre-defined masked regions, whose elemental constituents are selected from Groups III and V of the Periodic Table, which method provides free methyl radicals in a plasma environment using a gas including a methyl compound bonded to nitrogen.

In particular, methylamine (CH_3NH_2), dimethylamine ($(CH_3)_2NH$) and trimethylamine ($(CH_3)_3N$) can be used as the etch gas. Preferred substrate materials comprise InN, InP, InAs, InSb, InGaAs, InGaAsP, GaN, GaP, GaAs, GaSb, AlP, AlAs, AlSb, AlGaAs, AlGaN and AlGaInN compounds

Further, not only the above-mentioned materials, whose

surface elemental constituents are selected from Groups III and V of the Periodic Table, can be etched, but also materials whose surface elemental constituents are selected from Groups II and VI of the Periodic Table, with said etchant gas, but preferably using trimethylamine as the etchant gas. Preferred such materials comprise CdS, CdSe, CdTe, HgS, HgSe, HgTe, MgS, MgSe, MgTe, MnS, MnSe, MnTe, PbS, PbSe, PbTe, SnS, SnSe, SnTe, ZnS, ZnSe, ZnTe, CdHgTe and other alloys based on these compounds.

It may be preferred that the etch gas comprising a methyl compound bonded to nitrogen should be mixed with another gas. Such additional gas may comprise H_2, N_2, O_2, a rare gas (such as Ar) or a halogen-containing gas (such as Cl_2,BCl_3) or any combination of these.

It has been found that methods according to the embodiment of the present invention can reduce the disadvantage mentioned above in that a much smoother ion beam etched surface is produced.

Further, low polymer formation is expected due to preferential formation of methyl radicals over polymer-generating hydrocarbon radicals because of the lower bond energy for the former. This allows higher methyl containing gasflows to counter the preferential etching of the V elements, while maintaining a low polymer formation, which increases the parameter space useful for process optimisation.

Furthermore, it is possible to apply plasma etching

other than ion beam etching, in which is used the above-mentioned etching gas that has been formed into a plasma, by supplying microwave electric power with a magnetic field, supplying microwave electric power alone, supplying radio frequency electric power or supplying DC-power. This application leads to enhanced etching of the III element in a III/V compound material to counter preferential removal of the V element.

The invention may be performed in various ways and preferred embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a side view showing a structure of an inductively coupled plasma ion beam etching apparatus used in an etching method according to an embodiment of the present invention;

Figure 2 is a side view showing a structure of a parallel plate type plasma etching apparatus used in an etching method according to an embodiment of the present invention;

Figure 3 is a side view showing a structure of an electron cyclotron resonance (ECR) etching apparatus used in an etching method according to an embodiment of the present invention;

Figure 4 is a side view showing a structure of an inductively coupled plasma (ICP) etching apparatus used in an etching method according to an embodiment of the present

invention;

Figure 5 is a side view showing a structure of a barrel reactor plasma etching apparatus used in an etching method according to an embodiment of the present invention;

Figure 6 is a side view showing a structure of an electron cyclotron resonance plasma ion beam etching apparatus used in an etching method according to an embodiment of the present invention;

Figure 7A is a cross sectional view showing an InP sample with resist mask;

Figure 7B is a cross sectional view showing an etched InP sample after removal of the resist mark;

Figure 8 is scanning electron microscopy picture showing test structures in InP after etching based on an etching method according to an embodiment of the present invention; and

Figure 9 is a side view showing a structure of a diode type plasma etching apparatus used in an etching method according to an embodiment of the present invention.

Table 1 shows, by atomic force microscopy, the measured root mean square (rms.) roughness of InP surfaces etched using different energies. The first two columns show rms. roughness of InP surfaces etched by etching methods according to an embodiment of the present invention. The last column shows the rms. roughness of InP surfaces etched by standard Ar sputtering.

A method for etching an InP substrate according to the

embodiment of the present invention will now be described with reference to the drawings.

(1) Description of an inductively coupled radio-frequency plasma (ICP) ion beam etching system used in a method for etching an InP substrate according to an embodiment of the present invention.

In Figure 1, a plasma generating chamber 1 is used for forming plasma. The plasma is generated by inductive coupling of 13.56 MHz RF-power from a coil 6 to the plasma generating chamber 1. The RF-power is coupled from the coil 6 to the plasma generating chamber 1 through a dielectric coupling window 8 which isolates the vacuum in the plasma generating chamber 1 from the atmospheric pressure at the coil 6. An etching chamber 2 is connected to the plasma generating chamber 1 through an extracting grid 3 and an acceleration grid 4. Ions in the plasma generated in the plasma generating chamber 1 are accelerated towards an InP substrate 10 by applying a negative bias on the extraction grid 3 and a positive bias on the acceleration grid 4. The InP substrate 10 is placed on the substrate table 11 which is grounded with respect to the extraction grid 3 and the acceleration grid 4.

Permanent magnets 5 enhance the RF-power coupling from coil 6 to the gas plasma in the plasma generating chamber. The gas is injected to the plasma generating chamber 1 through the gas introduction holes 7. An exhaust port 9 is provided from the etching chamber 2, and excessive etching

gas and reacted gas are exhausted therethrough to the outside of the etching chamber.

This inductively coupled radio frequency plasma ion beam etching system has such features that the energy of the ions impinging on the target can be controlled in the range from a few eV up to 900 eV. Further, there is also the feature that etching can be made without significant heating of the substrate i.e. close to room temperature.

When the InP substrate 10 is etched, it is placed first on the substrate table 11. Then, trimethylamine ($(CH_3)_3N$) gas is introduced into the plasma generating chamber 1 through the gas introduction holes 7, and the RF-power is introduced into the plasma generating chamber 1 by inductive coupling from the coil 6 forming a plasma. Positive ion species from the plasma are accelerated towards the InP substrate 10 by the voltage obtained between the extraction grid 3 and the acceleration grid 4 by the applied grid biases. The ion energy of the ions impinging on the InP substrate 10 is determined by the bias applied to the acceleration grid 4 due to grounding of the substrate table 11. The impinging ions etch the InP substrate 10.

A parallel plate type etching apparatus such as shown in Figure 2, rather than the ion beam etching apparatus, may also be used. In this parallel type etching apparatus, RF electric power having frequency of 13.56 MHz is supplied between the opposed electrodes, thereby forming the etching

gas in an etching chamber into plasma so as to etch a substrate 1. The chamber has gas inlets 2 and a gas exhaust 3.

In a diode type etching apparatus as shown in Figure 9, RF electric power having a frequency of 13.56 MHz is supplied to the electrode, on which a substrate 1 is situated, thereby forming the etching gas in an etching chamber into plasma so as to etch a substrate. The walls of the chamber are grounded. The chamber has gas inlets 2 and a gas exhaust 3.

In the ECR etching apparatus of Figure 3, the chamber has a gas inlet 2 and a gas exhaust 3 and a mounting for a substrate 1. Microwave input is provided at 4 and magnets 5 are used to enhance the power coupling.

In the (ICP) type etching apparatus of Figure 4, again the chamber supports a substrate 1 and has a gas inlet 2 and a gas exhaust 3.

The barrel reactor etching apparatus of Figure 5 has a gas inlet 2 and a gas exhaust 3 and supports the substrate 1 as shown.

Further, an ion beam etching apparatus having any type of plasma source, and in particular an ECR plasma source such as shown in Figure 6 or an ICP source such as shown in Figure 1, may also be used. In Figure 6 the substrate is carried at 1 and the chamber has a gas inlet 2 and a gas exhaust 3. Voltage grids are provided, together with a magnet 5 used to enhance the power coupling and a microwave

input 6.

Although the following detailed description refers to the use of an Ion Beam Etching apparatus, other types of high and low density plasma tools which are well known to those skilled in the art (including those outlined above) can also be used.

(2) Description of a method for etching an InP substrate according to an embodiment of the present invention.

First, a resist is coated onto the InP substrate by a spin coating method. Then the coated resist is hardened by baking so as to form a resist film having a thickness 1.2μm. Then, the resist film is exposed selectively using a photo mask, and thereafter unnecessary portions are removed by soaking the substrate into a developer, thus completing a resist mask 12 having openings as shown in Figure 7A. In Figure 7A the substrate 1 is shown with a completed resist mask 12.

Next, using the inductively coupled plasma ion beam etching apparatus as shown in Figure 1, the InP substrate 10 with the resist mask is placed on the substrate table 11 in the etching chamber 2. Then, the interior of the etching chamber 2 and the interior of the plasma generating chamber 1 are exhausted.

After a predetermined base pressure is reached, trimethylamine gas is introduced into the plasma generating chamber 1 and the pressure is held at 1.0×10^{-4} Torr to

$6.0x10^{-4}$ Torr by varying the gas flow due to constant pumping speed. In case of the present embodiment, the pressure is held at $2.0x10^{-4}$ Torr and the trimethylamine gas flow is held, for instance, at 3 sccm. Furthermore, RF-power of 170 W is introduced to the plasma generating chamber 1. With this, the trimethylamine is formed into a plasma through inductively coupling of the RF-power. The plasma gas passes through the acceleration grid 4 and the extraction grid 3 into the etching chamber 2 and the ionised species are accelerated towards the InP substrate 10, impinging and thus starting etching. In other high density embodiments, the acceleration of the ionised species is achieved by means of applying an electrical bias, means of application being well known to those skilled in the art. This acceleration bias plays a critical role during the etching process. After etching, the resist mask is removed by acetone as shown on Figure 7B. Any remaining resist residuals are removed by oxygen plasma treatment.

(3) Next the results of the above etching will be described.

Figure 8 shows a scanning electron microscopy picture of an etched test structure in InP after etching for 30 min having a trimethylamine flow of 3 sccm and a pressure at $2.0x10^{-4}$ Torr. The biases on the extraction grid 3 and the acceleration grid 4 were kept at -300 V and +300 V respectively with respect to the grounded substrate table

11.

Table 1 shows the rms. roughness of etched InP surfaces measured by atomic force microscopy. The etch depths are in all cases 200 nm.

Column 1 in table 1 shows the rms. roughness of InP surfaces etched using trimethylamine (TMA) gas as described above for different energies of the impinging ions. Only the acceleration grid voltage and the process time were varied while all other parameters were kept constant.

Column 2 in table 1 shows a diagram of the rms. roughness of InP surfaces etched as described above, but with a mixture of trimethylamine (TMA) and Ar gas at different energies of the impinging ions. Only the acceleration grid voltage and process time were varied while all other parameters were kept constant. The etching was performed under similar conditions as those demonstrated in column 1 in table 1 and in the same etching apparatus. Gas flows of trimethylamine and Ar were 3 sccm and 5 sccm respectively.

Column 3 in table 1 shows a diagram of the rms. roughness of InP surfaces etched using standard Ar sputtering with different ion energies of the impinging ions. Only the acceleration grid voltage and process time were varied while all other parameters were kept constant. The etching was performed under similar conditions as those demonstrated in column 1 in table 1 and in the same etching apparatus. Ar gas flow was 5 sccm.

From the result of the atomic force microscopy observation, it is seen that the trimethylamine based process can produce extremely smooth morphologies (i.e. low rms. roughness) compared to standard Ar milling. Thus by using an etching method of an embodiment of the present invention, it is possible to obtain extremely smooth etched InP surface morphologies.

Claims

1. A method of etching a substrate provided with pre-defined masked regions, whose elemental constituents are selected from Groups III and V or from groups II and VI of the Periodic Table, comprising the steps of: a) forming a gas containing molecules having at least one methyl group (CH_3) linked to nitrogen into a plasma; and b) etching the unmasked regions of the substrate by means of the plasma.

2. The method according to Claim 1, wherein said etching gas is selected from the group consisting of methylamine (CH_3NH_2), dimethylamine ($(CH_3)_2NH$) and trimethylamine ($(CH_3)_3$ N).

3. A method of etching a substrate provided with pre-defined masked regions, whose elemental constituents are selected from Groups II and VI of the Periodic Table, comprising the steps of: a) forming an etching gas comprising trimethylamine ($(CH_3)_3N$) into a plasma; and b) etching the unmasked regions of the substrate by means of the plasma.

4. The method according to any one of Claims 1 and 3, wherein said etching gas is mixed with another gas selected from H_2, N_2, O_2, Ar or another rare gas, or Cl_2, BCl_3 or other halogen-containing gas or any combination of these.

5. A method according to any one of Claims 1 to 4, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power with a

magnetic field to the etching gas.

6. A method according to any one of Claims 1 to 4, wherein said step (a) comprises forming the gas into a plasma by supplying microwave electric power to the etching gas.

7. A method according to any one of Claims 1 to 4, wherein said step (a) comprises forming the gas into a plasma by supplying radio frequency electric power to the etching gas.

8. A method according to any one of Claims 1 to 4, wherein said step (a) comprises forming the gas into a plasma by supplying DC electric power to the etching gas.

9. A method according to any one of Claims 1 to 8, wherein the ions are accelerated by a DC bias.

10. A method according to Claim 9, wherein said DC bias creates energy in the range of 0-2000 eV.

11. A method according to any one of Claims 1 to 8,wherein the applied power is converted to an ion energy in the range of 0-2000 eV.

12. Any combination of novel features of a method of etching a substrate provided with pre-defined masked regions, substantially as herein described and/or as illustrated in the accompanying drawings.

ABSTRACT

"Improvements relating to plasma etching

A substrate whose elemental constituents are selected from Groups III and V of the Periodic Table, is provided with pre-defined masked regions. Etching of the substrate comprising the steps of: a) forming a gas containing molecules having at least one methyl group (CH_3) linked to nitrogen into a plasma; and b) etching the unmasked regions of the substrate by means of the plasma. For a substrate whose elemental constituents are selected from Groups II and VI of the Periodic Table, the plasma etching gas used is trimethylamine. Since the methyl compound of nitrogen has a lower bond energy than for hydrocarbon mixtures, free methyl radicals are easier to obtain and the gas is more efficient as a methyl source. In addition, compared with hydrocarbon mixtures, reduced polymer formation can be expected due to preferential formation of methyl radicals over polymer-generating hydrocarbon radicals because of the lower bond energy for the former.

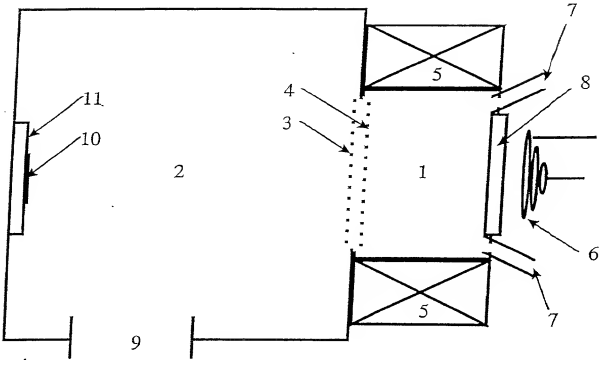


Fig. 1

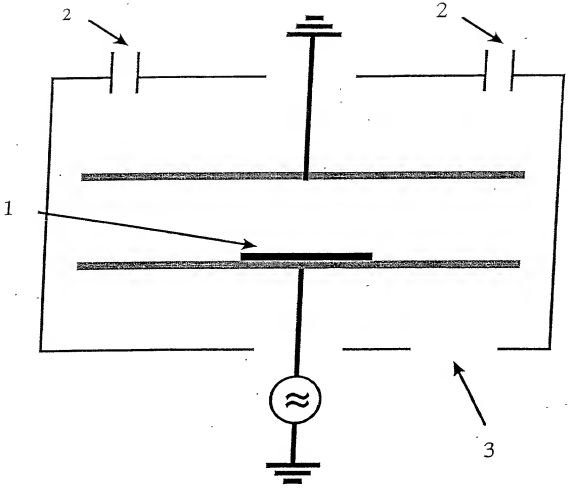


Fig. 2

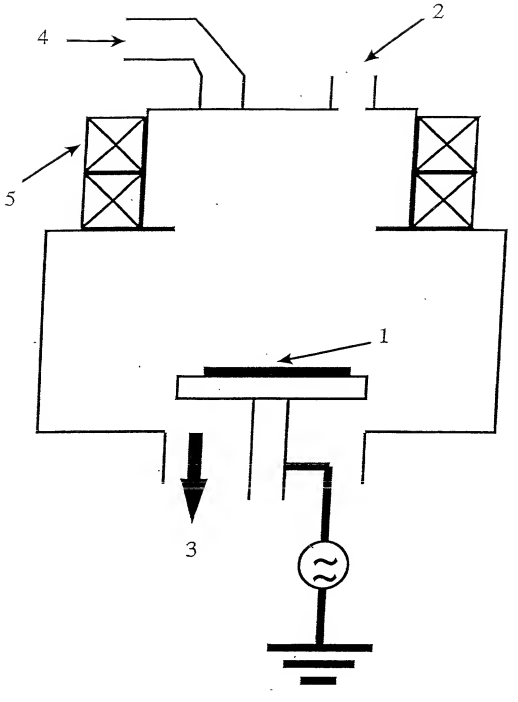


Fig. 3

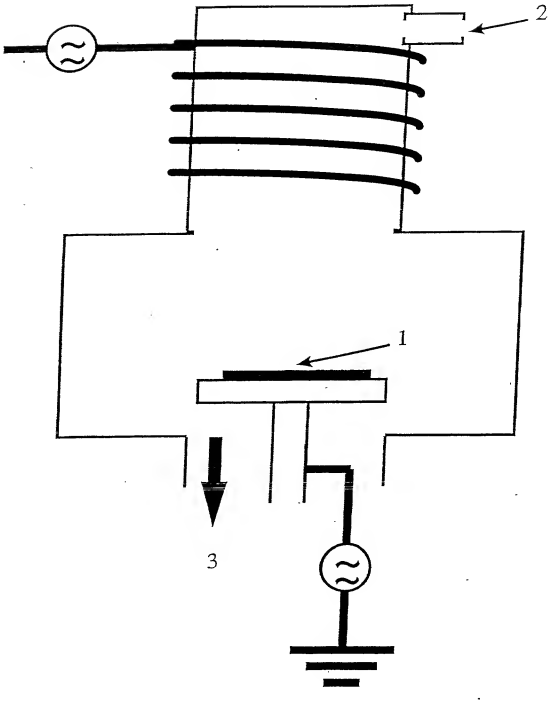


Fig. 4

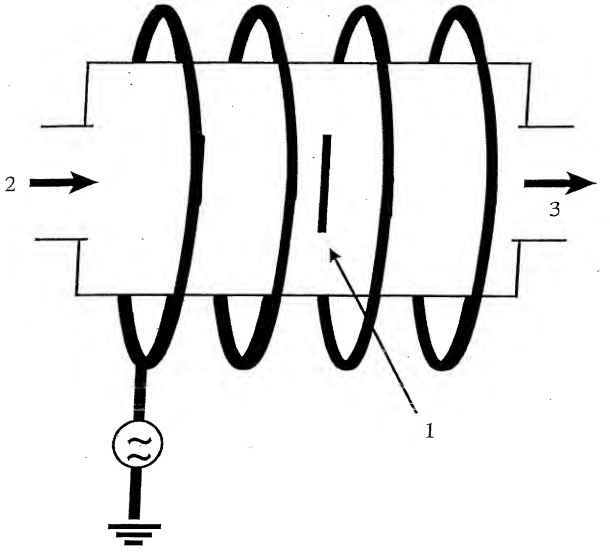


Fig. 5

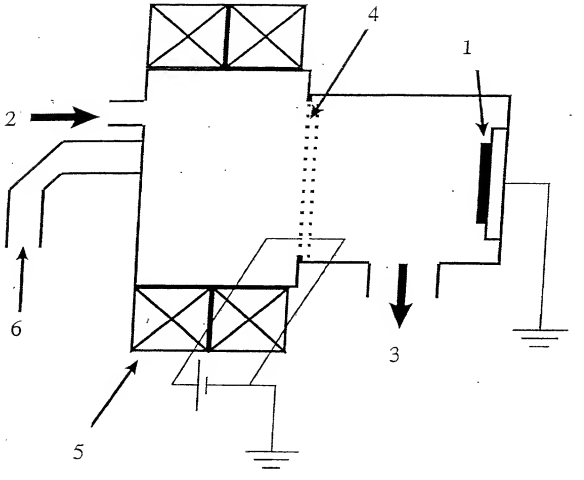
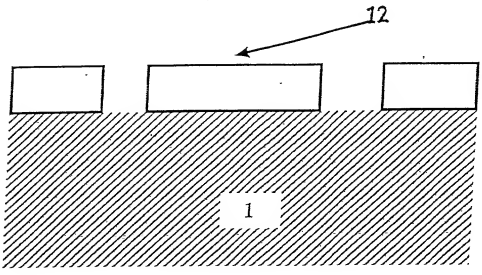


Fig. 6

A;



B;

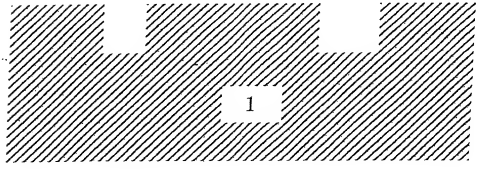


Fig. 7A-B

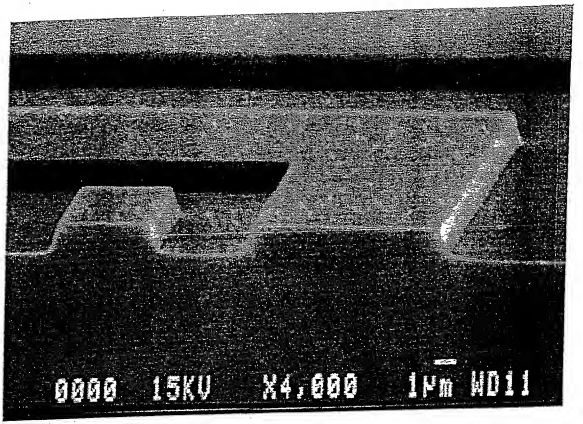


Fig. 8

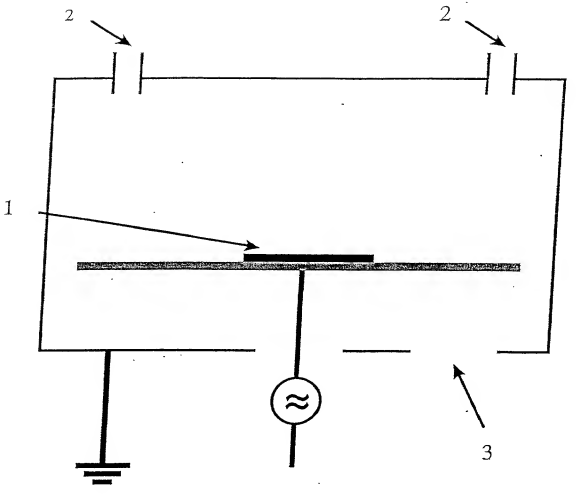


Fig. 9

ION ENERGY	PROCESS GAS: TMA	TMA + Ar	Ar
75 eV	0.65 nm	0.15 nm	4.80 nm
150 eV	0.16 nm	0.19 nm	3.90 nm
300 eV	0.26 nm	0.24 nm	13.70 nm
500 eV	0.39 nm	1.1 nm	7.30 nm

Table 1

DECLARATION AND POWER OF ATTORNEY FOR U.S. PATENT APPLICATION

(X) Original ( ) Supplemental ( ) Substitute ( ) PCT ( ) Design

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; that I verily believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

TITLE: IMPROVEMENTS RELATING TO PLASMA ETCHING

of which is described and claimed in:

( ) the attached specification, *or*

( ) the specification in the application Serial No._____ filed_____,

and with amendments through_____ (if applicable), *or*

(X) the specification in International Application No. PCT/GB00/02255, filed JUNE 21, 2000 ,

and as amended on _____ (if applicable).

I hereby state that I have reviewed and understand the content of the above-identified specification, including the claims, as amended by any amendment(s) referred to above.

I acknowledge my duty to disclose information of which I am aware which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 (and §172 if this application is for a Design) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

COUNTRY	APPLICATION NO.	DATE OF FILING	PRIORITY CLAIMED
SWEDEN	9902344-2	21 JUNE 1999	YES
SWEDEN	9903213-8	10 SEPTEMBER 1999	YES

I hereby claim the benefit under Title 35, United States Code, §120 and §119(e) of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

APPLICATION SERIAL NO.	U.S. FILING DATE	STATUS: PATENTED, PENDING, ABANDONED

And I hereby appoint Adam C. Volentine, Reg. No. 33,289 and William S. Francos, Reg. No. 38,456, and the firm of VOLENTINE FRANCOS, P.L.L.C., jointly and severally, attorneys to prosecute this application and to transact all business in the U.S. Patent and Trademark Office connected therewith.

I hereby authorize the U.S. attorneys named herein to accept and follow instructions from WYNNE-JONES, LAINE & JAMES as to any action to be taken in the U.S. Patent and Trademark Office regarding this application without direct communication between the U.S. attorneys and myself. In the event of a change in the persons from whom instructions may be taken, the U.S. attorneys named herein will be so notified by me.

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Post Office Address	ADDRESS	CITY	STATE OR COUNTRY	ZIP CODE

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Residence & Citizenship	CITY	STATE OR COUNTRY	COUNTRY OF CITIZENSHIP	
Post Office Address	ADDRESS	CITY	STATE OR COUNTRY	ZIP CODE

I further declare that all statements made herein of my own knowledge are true, and that all statements on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1st Inventor _____ Date 4th JAN 2002
Anand SRINIVASAN

2nd Inventor _____ Date 4th Jan 2002
Carl-Fredrik CARLSTROM

3rd Inventor _____ Date 4th Jan 2002
Gunnar LANDGREN

4th Inventor _____ Date _____

5th Inventor _____ Date _____

****

Applicant Reference No.: STS.038 Atty Docket No.: WLJ.078